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A Synthesis of Engineering and Business Best-Practices to Achieve Breakthroughs in Flight Hardware Delivery[1,2]

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FLIGHT HARDWARE FHLP LOGISTICS PROGRAM

Abstract—Development and use of leading-edge engineering and business practices by the best and brightest provides firm footing for the tremendous advances in the aerospace community. Applied together and systemically across multiple missions, these practices can yield tremendous breakthroughs in the reduction of technical, schedule and cost risk for project development. An example of this synthesis can be found in the Jet Propulsion Laboratory's Flight Hardware Logistics Program (FHLP), which uses space systems engineering expertise and supply-chain business acumen to achieve breakthroughs in the delivery of space flight hardware.

To support the evolution from a few large projects to many smaller projects developed in shorter time, flight hardware delivery must transform from serial, independent and resource-intensive processes to those characterized by commonality, multi-project support, anticipation, industry-partnering, re-use and easy access to information. These are the foundation processes for the communication, coordination and collaboration that FHLP provides to enhance JPL project success.

The heart of FHLP centers on the commonality of flight hardware across multiple projects. As an example, FHLP has demonstrated significant schedule, cost and technical risk reduction using a common buy of 31 flight computers for 9 different projects. Understanding and coordinating similar product requirements for multiple subsystems, instruments, projects and companies can yield even greater savings.

Knowledge of upcoming missions, their flight product needs, hardware capabilities and supply sources combine to develop anticipatory procurements of flight hardware to reduce or eliminate lead-time. Compensation from the users replenishes the supply. This is being accomplished for flight electronic parts, connectors and fasteners.

Partnering with industry is achieved both with suppliers and users of hardware. Open contracts and advanced parts buys are examples of supplier agreements while synchronized procurement and inventory exchange are examples of user agreements between JPL and its contractors.

Improved tracking, coordination, record keeping and storage of residual flight hardware can provide crucial cost and schedule benefits to future projects. FHLP has developed a low-cost, user-controllable, JPL-wide system and facilities to significantly increase the capability for project use of past projects' residual material.

Having the right hardware information at the engineer's fingertips saves considerable time and reduces the risk of missing important past knowledge. FHLP provides limited hardware information today; tomorrow it will provide much more comprehensive "one-stop shopping." FHLP's arsenal of information tools include an on-line JPL-wide hardware catalog (with reports, shopping carts and digital pictures), project usage database and program library.

The many simultaneous smaller projects implemented today do not enjoy the substantial infrastructure and stable expertise more prevalent with past fewer large projects. FHLP fills these gaps with services of hardware information, availability, investigation, delivery and storage. Likewise, proposed projects hungry for higher fidelity, increased heritage and lower costs welcome a menu of support from FHLP that includes information about available hardware, hardware costs, lead times and suppliers.

FHLP's early focus on hardware delivery and inventory will be augmented by enhanced hardware information and expand to include other NASA Centers and industry partners. Our breakthroughs will be limited only by our imagination, innovation, commitment and energy.

[2] IEEE Aerospace Conference paper #450, Updated Sept 30, 2001

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1. INTRODUCTION

Environment Changes

The space mission development environment has undergone changes from the past to present. A number of these key changes are shown in Table 1. What is clear from these changes is that our approaches to the development process must also undergo transformation to respond to these environmental changes.

Project Characteristic	Past	Present
Project Size	Large	Small
Personnel	Stable	Transitory
Workforce	Dedicated	Shared
Number of Projects	Few	Many
Number of different ways to do business	Few	Many
Development Time	Long	Short
Technical Risk	Lowest	Affordable
Cost Growth	Common	Capped
Schedule Delays	Common	Cancellation
Infrastructure	Supported	Uncertain
Expertise	Centralized	Fragmented
Knowledge transfer	People	Practices
Commonality	Low	Moderate

Table 1. Environmental Changes

FHLP Challenges

The challenging space missions of today push the boundaries of program management and system engineering to balance schedule, cost and technical risks while achieving exciting mission objectives. A valuable approach to meeting these challenges is to reduce the development time, otherwise known as cycle time, for space systems development (Figure 1). Since the mid-1990's, JPL has been re-engineering its business and engineering practices to reduce this cycle time by one-half. An example of this would be to reduce the 36-month cycle time of Mars Pathfinder to 18 months.

A significant problem in meeting this cycle time reduction is the acquisition of flight hardware. Many flight hardware items can take 12 months or longer to procure from industry. This precludes missions where the development time is significantly reduced. In order to meet this cycle time challenge, the acquisition cycle must be compressed. It is this compression challenge that was the basis for forming Jet Propulsion Laboratory's Flight Hardware Logistics Program (FHLP) in 1997.

In addition to this initial challenge to compress the acquisition cycle, a number of other flight hardware challenges arise in the transition from a few large projects of the past to many smaller projects today:

a. Limited communication, coordination and collaboration
b. Limited commonality
c. Hardware logistics inefficiency
d. Diffused expertise
e. Variety in hardware pedigree records maintenance
f. Limited post-project residual inventory tracking
g. Difficult hardware information access

In an environment where many smaller projects cannot individually develop capabilities to solve these challenges coupled with strained institutional resources, entirely new approaches need to be developed. These approaches must generate breakthroughs to meet these flight hardware delivery challenges.

FHLP combines best practices synergistically from both engineering and business disciplines to achieve such breakthroughs. Critical to FHLP success is the application of flight hardware and system engineering expertise to the business processes of acquisition, logistics and finance. Through combination, gains far greater than the sum of these individual practices are realized for hardware delivery.

FHLP Concept

For FHLP to meet these challenges, a number of general approaches are used (Figure 2). Common buys of long lead-time or high use hardware items are conducted across multiple projects. Anticipatory buys of hardware develop inventories ready for immediate project use. Supplier agreements prime the supply chain to fulfill projects' needs on demand. Residual inventory provides instantly available hardware for project use. Design engineers find an easily

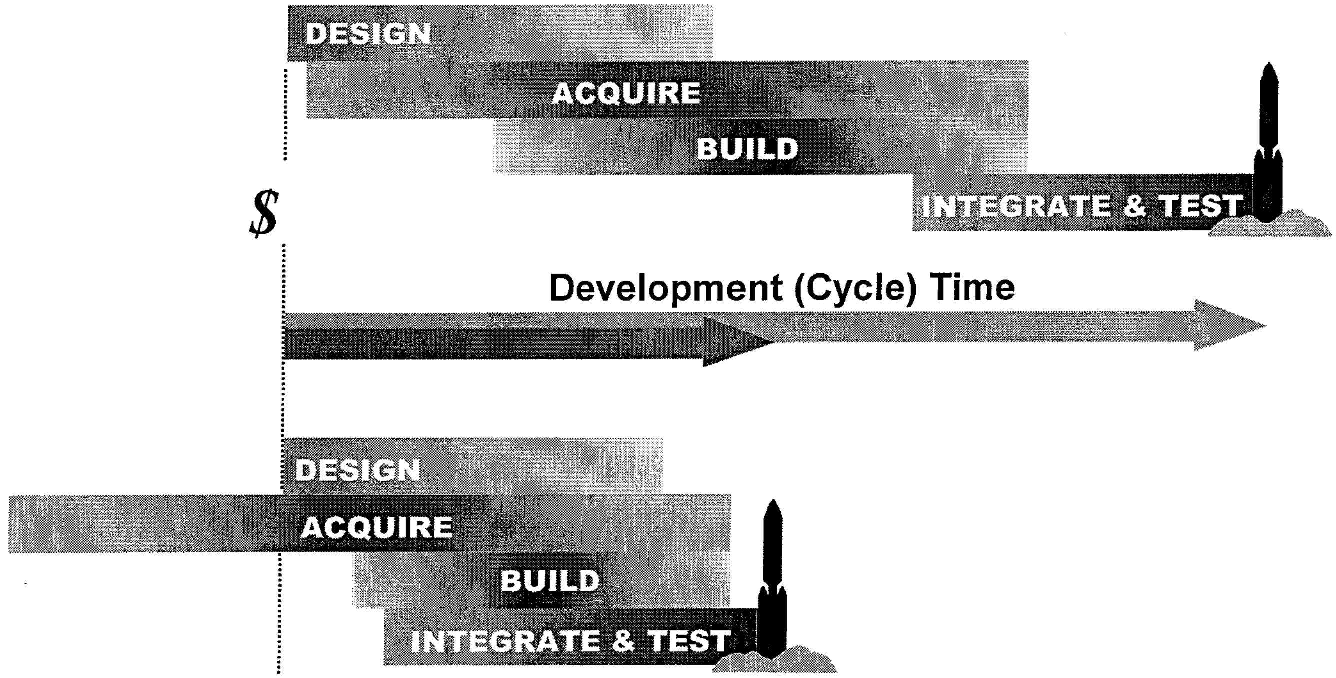


Figure 1. FHLP Challenge

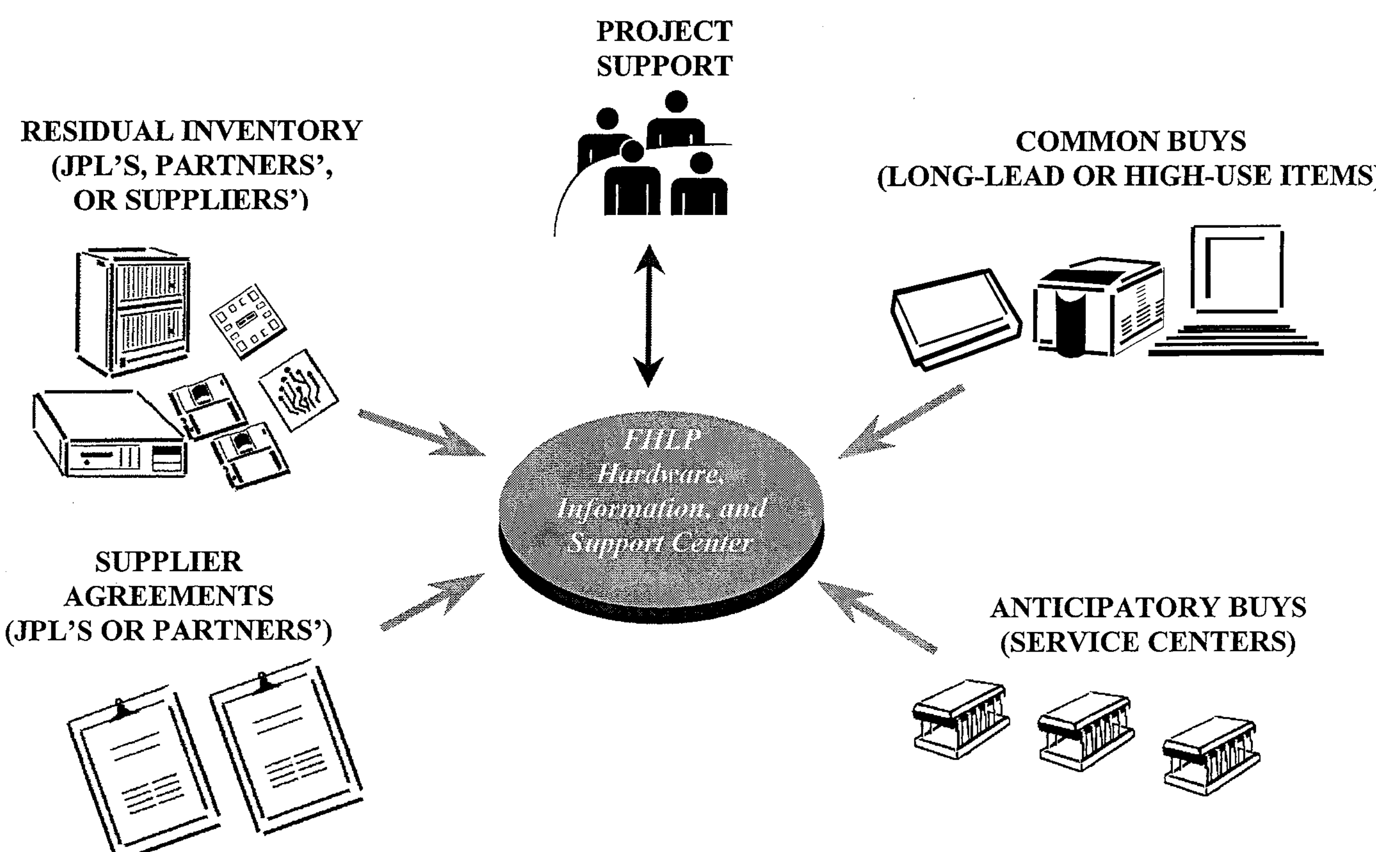


Figure 2. FHLP Concept

accessible source of hardware information. Direct support to projects is provided in hardware logistics, inventory searches, investigation, information access and proposal development. All of these approaches are funded by a combination of direct project funding and institutional support. The overall implementation of these approaches is shown in Figure 3, where the Fiscal Year begins in the prior year October and runs through September of the Fiscal Year.

Approach

The approach for common buys is comprised of several sets of activities: marketing, engineering, management, acquisition and infrastructure.

Marketing–The first step in developing and implementing common buys is to develop a thorough understanding of potential customer needs. To do this, a frequently updated

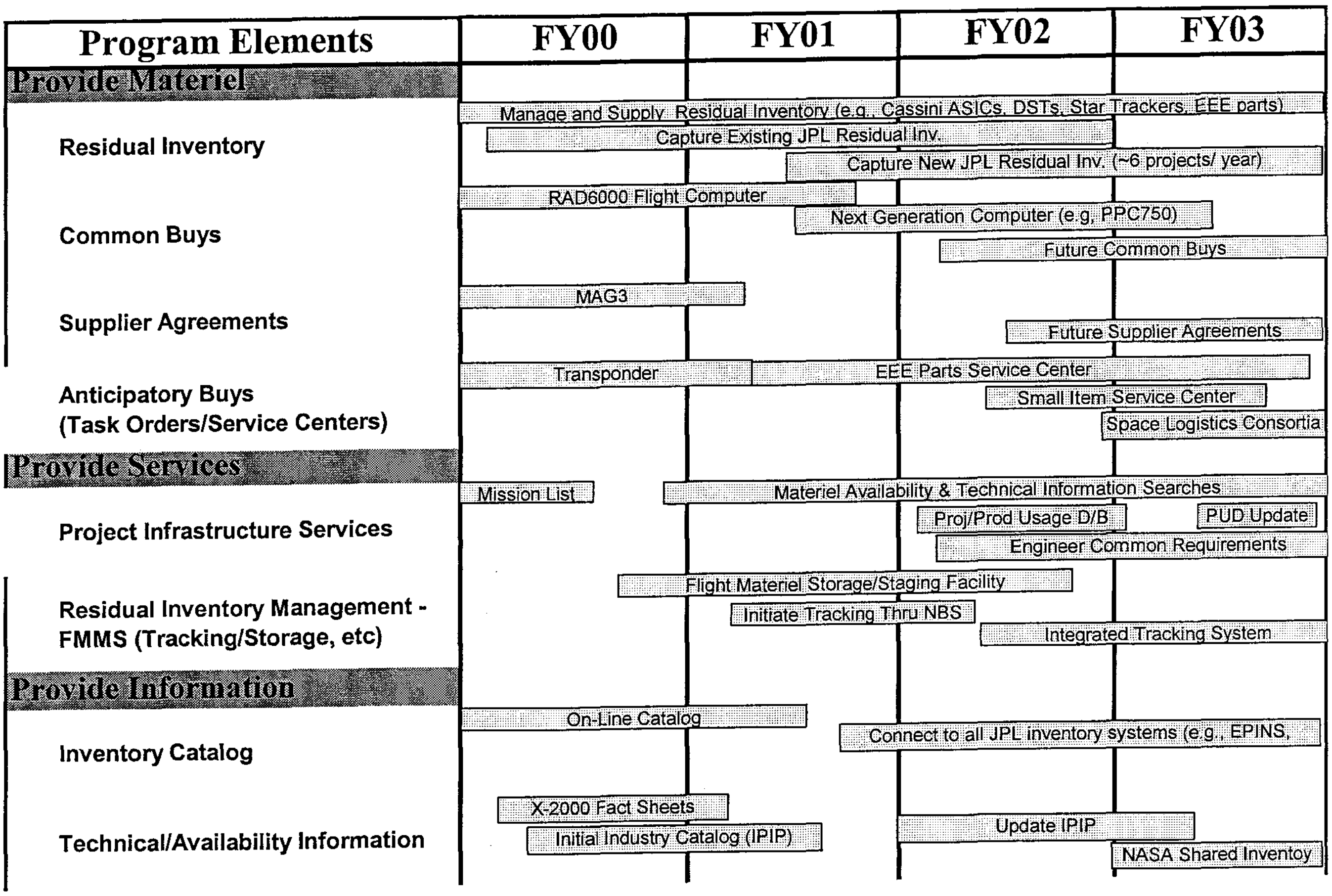


Figure 3 – Overall FHLP Implementation

2. Common Buys

Concept

Flight hardware used by multiple projects can be considered for common procurement if the projects' schedule and cost profiles are closely aligned. Common buys can also be considered for long lead-time hardware.

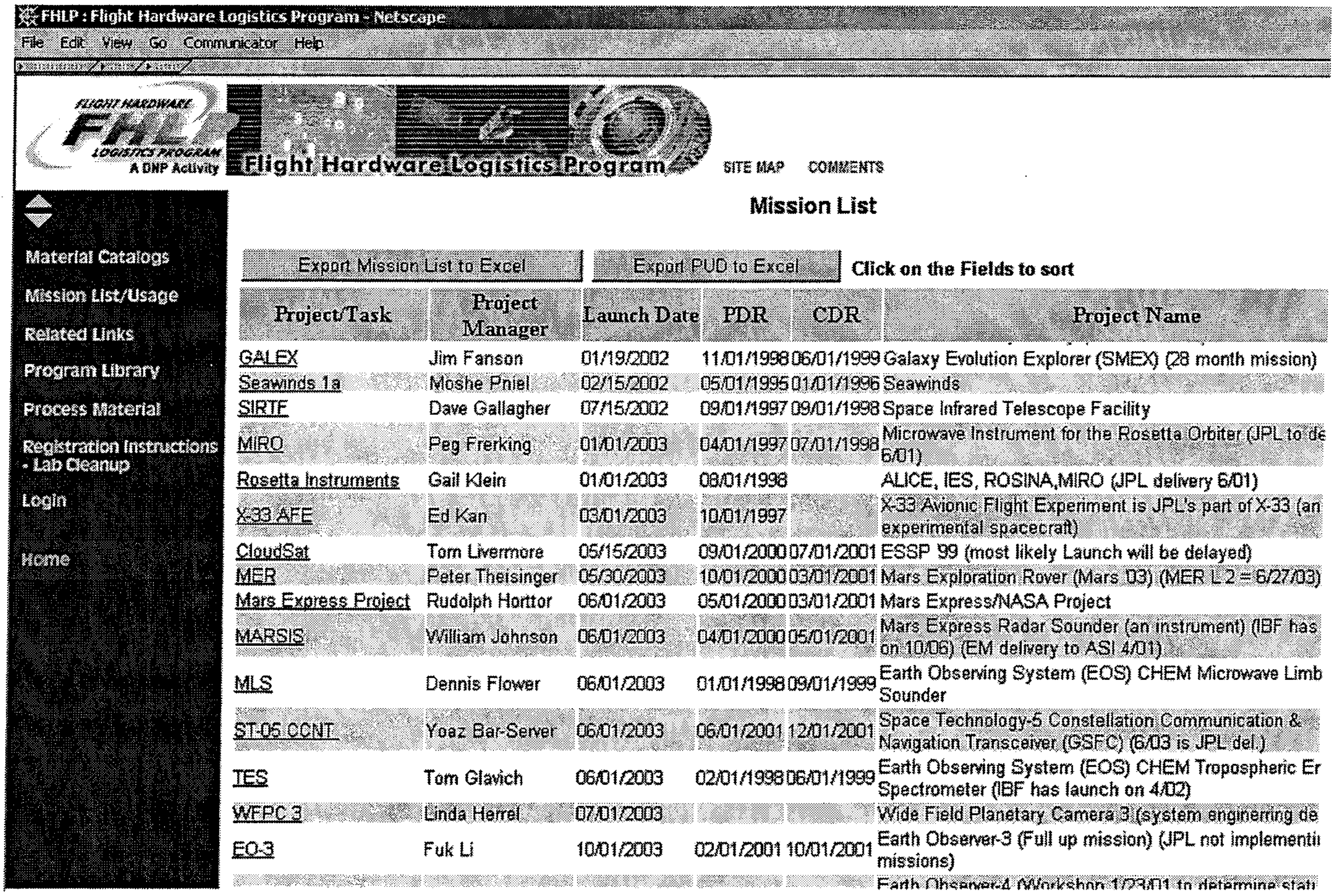
Rationale

Common buys have significant advantages, including:

1) Cost savings through "volume discount"
2) Risk reduction through multi-project sharing
3) Schedule savings through production efficiencies and advance inventories
4) Common infrastructure across projects

"Mission List" of all projects with their respective launch, Preliminary Design Review (PDR) and Critical Design Review (CDR) dates is maintained by FHLP (Figure 4). From this Mission List, FHLP maintains a Project Usage Database (PUD), which identifies hardware used by each project in various subsystems and assemblies (Table 2). Combined, the Mission List and PUD provide sufficient visibility and timing for future customer hardware needs.

Engineering–The next common buy step is to match customer requirements with product capabilities. Customer requirements shown in the PUD are analyzed to determine the most valuable common buy opportunities (for example, in Table 2, it appears that an SDST is an obvious common buy). This involves determining what functional, assurance, environmental and programmatic requirements exist or are predicted to exist for each candidate project. At this point, significant discussion occurs with each project and with all


FHLP : Flight Hardware Logistics Program - Netscape

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FLIGHT HARDWARE LOGISTICS PROGRAM A DNP Activity

Flight Hardware Logistics Program

SITE MAP COMMENTS

Material Catalogs
Mission List/Usage
Related Links
Program Library
Process Material
Registration Instructions - Lab Cleanup
Login
Home

Mission List

Export Mission List to Excel | Export PUD to Excel | Click on the Fields to sort

Project/Task	Project Manager	Launch Date	PDR	CDR	Project Name
GALEX	Jim Fanson	01/19/2002	11/01/1998	06/01/1999	Galaxy Evolution Explorer (SMEX) (28 month mission)
Seawinds 1a	Moshe Pniel	02/15/2002	05/01/1995	01/01/1996	Seawinds
SIRTF	Dave Gallagher	07/15/2002	09/01/1997	09/01/1998	Space Infrared Telescope Facility
MIRO	Peg Frerking	01/01/2003	04/01/1997	07/01/1998	Microwave Instrument for the Rosetta Orbiter (JPL to de 6/01)
Rosetta Instruments	Gail Klein	01/01/2003	08/01/1998		ALICE, IES, ROSINA,MIRO (JPL delivery 6/01)
X-33 AFE	Ed Kan	03/01/2003	10/01/1997		X-33 Avionic Flight Experiment is JPL's part of X-33 (an experimental spacecraft)
CloudSat	Tom Livermore	05/15/2003	09/01/2000	07/01/2001	ESSP 99 (most likely Launch will be delayed)
MER	Peter Theisinger	05/30/2003	10/01/2000	03/01/2001	Mars Exploration Rover (Mars 03) (MER L 2 = 6/27/03)
Mars Express Project	Rudolph Horttor	06/01/2003	05/01/2000	03/01/2001	Mars Express/NASA Project
MARSIS	William Johnson	06/01/2003	04/01/2000	05/01/2001	Mars Express Radar Sounder (an instrument) (IBF has on 10/06) (EM delivery to ASI 4/01)
MLS	Dennis Flower	06/01/2003	01/01/1998	09/01/1999	Earth Observing System (EOS) CHEM Microwave Limb Sounder
ST-05 CCNT	Yoaz Bar-Server	06/01/2003	06/01/2001	12/01/2001	Space Technology-5 Constellation Communication & Navigation Transceiver (GSFC) (6/03 is JPL del.)
TES	Tom Glavich	06/01/2003	02/01/1998	06/01/1999	Earth Observing System (EOS) CHEM Tropospheric Er Spectrometer (IBF has launch on 4/02)
WFPC 3	Linda Herrel	07/01/2003			Wide Field Planetary Camera 3 (system engineering de
EO-3	Fuk Li	10/01/2003	02/01/2001	10/01/2001	Earth Observer-3 (Full up mission) (JPL not implementi missions)
					Earth Observer-4 (Workshop 1/23/01 to determine stat

Figure 4 – Mission List

projects together to obtain consensus that the subject product capabilities will satisfy each project's requirements. Any requirements not satisfied should be resolved (e.g., waivers, unique testing) at this time. It is crucial that sufficient review by customer project representatives occur at this time and consensus is documented in a Memorandum Of Understanding (MOU). This MOU should address delivery schedule, applicable requirements, cost sharing, shared sparing approach and necessary product information.

Management–Management of the common buy process occurs at all steps of the way, but the primary step at this point is securing the necessary workforce and financial resources to acquire the hardware. Workforce necessary includes procurement, contract technical management, engineering support, mission assurance, logistics and financial personnel. Financial resources include project financial resources as well as the financial mechanisms.

Project/Task	Launch Date	Product	Qty
Genesis	8/8/2001	CALTRAC SP-0941-10002/B04 Wide Angle	4
Genesis	8/8/2001	Digital 2-axis Sun Sensor #45280	4
SIM	4/1/2009	High Gain Antenna	1
Genesis	8/8/2001	Nutation Damper Tubular 1.75"DIA	4
Seawinds 1a	2/1/2002	RAD 6000 Flight Computer	2
Seawinds 1a	2/1/2002	RS-422 Serial Interface Board	2
Deep Impact	1/4/2004	SDST(Small Deep Space Transponder)	2
MER	5/30/2003	SDST(Small Deep Space Transponder)	3
Pluto/Kupier Express	6/1/2005	SDST(Small Deep Space Transponder)	2
Starlight	7/1/2006	SDST(Small Deep Space Transponder)	2
Solar Probe	2/1/2008	SDST(Small Deep Space Transponder)	2
Europa Orbiter	3/1/2008	SDST(Small Deep Space Transponder)	3

Table 2 – Project Usage Database

Financial mechanisms can include direct project funding, future funding by program offices which projects are part of, a task order from NASA directly funding the common buy, a task order from NASA allowing funding through supported projects with reimbursement to an FHLP task order or an internal Service Center where projects reimburse JPL for hardware supplied.

Acquisition–The next step is actually developing and implementing the common procurement. This involves extensive coordination with procurement personnel to develop the procurement package, sending it to industry, evaluating proposals and selecting the industrial partner. In developing and negotiating the contract with industry, it is crucial that the customer projects' requirements and needs are communicated and addressed such that the maximum commonality is achieved. After contract placement, it is crucial that the build process be monitored, issues are promptly addressed and delivery commitments are met.

Infrastructure–As deliveries are made to customers, there is a significant amount of information and application experience generated and significant need to support project customers. It is necessary to provide an efficient infrastructure to address these needs. This infrastructure includes experts, knowledge, documentation (paper and electronic), support personnel, test hardware and software. Content includes test reports, build records, end item data packages, certificates of conformance, specifications, application notes, environmental requirements, waivers and failure reports. Support required by projects includes investigating and resolving issues, retrieving hardware information, coordinating hardware logistics (e.g., storage, transportation, quality assurance, security) and searching for inventory.

Example

RAD6000–The best FHLP common buy example is the RAD6000 flight computer (Figure 5), manufactured by BAE Systems (previously Lockheed Martin) in Manassas, VA.

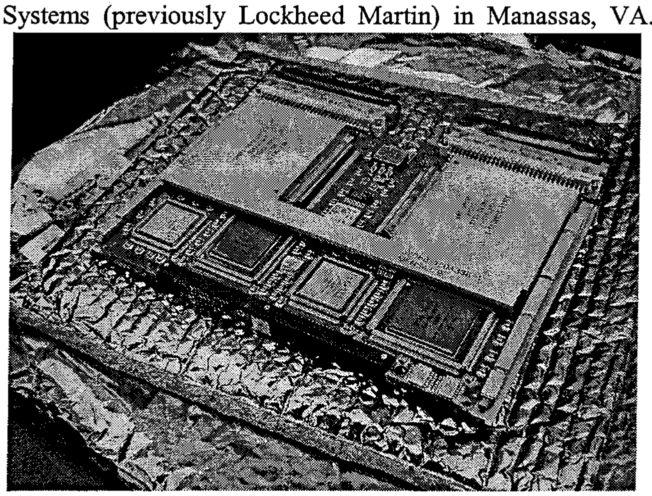


Figure 5 – RAD6000 Flight Computer

31 flight computers (and 2 breadboards) were bought for 9 projects, including 2 that were shared spares held by FHLP for all projects. The customer projects had planned launch dates that ranged over 26 months when this common buy was implemented.

A significant amount of effort went into estimating the cost (contractual, JPL labor, additional testing, reserve) and developing a Memorandum Of Understanding (MOU) between all customer projects that provided the detailed agreements for the common buy. It was also necessary to coordinate closely with the industrial partner on applicable projects to ensure that this Government Furnished Property (GFP) dovetailed into their development seamlessly.

Results

For the RAD6000 example, the projects collectively saved over \$3.7M in acquisition costs, enjoyed significant schedule reserve and shared risk mitigation. Another benefit to the projects was the delegation of this critical hardware delivery to FHLP, thereby saving project resources for other functions.

Although the Projects saved over \$3.7M in acquisition costs directly attributable to this common buy, much more money was saved in the common infrastructure, experience and risk mitigation shared by all the customer projects. An example of this was the shared investigation and resolution for a late-breaking concern which was successfully resolved in part due to the large quantity of computers that could be deployed across the various projects' integration and test activities.

This RAD6000 computer common buy became the pre-cursor for the next generation common buy of Power PC 750 computers (from BAE Systems) currently underway to support 3 projects with 5 breadboards, 6 engineering models and 6 flight computers.

Lessons Learned

Hardware heritage–Ensure that the heritage for flight hardware is carefully scrutinized by all the appropriate technical, assurance and project personnel, issues are addressed and disposition is fully documented. It is particularly important to review any changes from the heritage baseline to ensure that they are adequately qualified to the customer requirements.

Adequate resources–Ensure that adequate resources, such as the Contract Technical Manager, necessary support personnel and appropriate reserve are planned into the negotiated cost estimate that all projects approve. Ensure that projects are charged for the services they receive at the time the service is rendered.

Early assurance and project documented buy-in–Ensure that mission assurance and key project personnel document their acceptance of the common buy hardware to meet project requirements or that projects have approved waivers if needed.

Document problems and resolutions–Keep a running list of problems with status/resolution, final disposition acceptance and rationale. This minimizes re-education of new personnel later in the common buy cycle.

Ensure financial commitments are met–Implement financial mechanisms that commit project funds up front and charge projects as they receive the services.

Future Opportunity: Inter-project system engineering

Expanding this common buy concept to cross-project product requirements commonality and continuing to encourage capabilities-driven is a valuable next step. One approach to doing this might include:

1) Develop and operate small teams organized into subsystems that would flesh out driving requirements, key component types, key components and key manufacturers.
2) Develop a common database of key project requirements and products planned for use on each project
3) Analyze requirements/products trades and sensitivities to mission requirements to minimize differences
4) Develop projects' consensus on common requirements/products
5) Implement common buys to meet highest yield common products for projects

3. ANTICIPATORY BUYS

Concept

A key strategy to shortening the hardware delivery time is to anticipate project's needs and develop inventories (both real and virtual) to provide rapid availability of flight hardware. Virtual inventories are addressed by the supplier agreement portion of FHLP while real anticipatory inventories require a reasonable investment risk approach. This reasonable investment typically means that the customer projects or institution will forward-fund anticipatory buys of hardware that have a high probability of use by future projects. This risk profile usually translates into an investment in low-cost, high-reuse hardware.

Rationale

Having standard hardware available on-the-shelf for projects in anticipation of their needs significantly increases the efficiency of the institutional resources as well as providing strong incentives for project to use this material, which decreases project schedule, cost and technical risk.

Approach

Since anticipatory buys to create real inventory involve investment risk, it is important to begin this process with a thorough market analysis [1] of products considered for anticipatory buy that include:

1) Acquisition time (Lead-time)
2) Acquisition cost
3) Quantity used across projects
4) Maturity
5) Obsolescence
6) Cost savings using common buy

A more detailed version of this analysis for low-cost high-volume hardware such as flight electronic parts must include an analysis of potential use as well as inventory replenishment.

Funding options are similar to those for common buys where the inventory replenishment is funded from cost recovery for delivered hardware.

Example

The Flight Electronic Part Service Center (FEPSC) is the best example to date of an anticipatory buy mechanism. This Service Center buys parts for its own institutional stock with institutional funds and is reimbursed for parts that are bought or delivered per project request. The institution has also contributed to this effort to inventory long lead common use parts. Once project requested inventory no longer is needed, this inventory can be provided to other projects which reimburse the Service Center for inventory replenishment.

Another feature of the FEPSC is that all the required engineering and acquisition labor required for project and anticipatory parts buy support is charged through the FEPSC at a rate that generates a small budget for FEPSC management, administration, engineering and acquisition support.

In order to develop the anticipatory parts buy for the FEPSC, several data sources are analyzed and used:

1) Recent (last 1-2 years) purchased parts history
2) Current project parts requests
3) Projected future needs determined from designers and parts specialists

Results

In this first year of FEPSC operation (plus an additional month last year), it has bought over \$10M worth of electronic parts (quantity of about 300,000 parts consisting of 8,000 part types/values), of which about \$563k was institutionally funded (quantity of 4277 parts consisting of

58 different part types/values) and the remainder was bought to stock project requests.

Replenishment and anticipatory income has approached $1M and is expected to double in the next year as unused project requested parts are supplied to new projects and the FEPSC is reimbursed. Within a few years of constantly increasing replenishment, the long lead-time of flight electronic parts will largely become a faded memory in project development.

Lessons Learned

Commitment–It is crucial that the institution and projects be committed to this concept, since they are investing in a future inventory by paying a slightly higher rate today. It helps to show the savings afforded by a more coordinated effort that offsets (if not negates) this increase.

Financial–Several financial considerations must be taken into account. First, since the institution is buying all the hardware with eventual reimbursement by the projects when the requested hardware arrives, mechanisms must be in place to ensure that these commitments are honored. Using a Service Center with customer Work Orders has proven to be far stronger than simple MOUs used for common buys.

Second, it is important that the Service Center be able to carry a non-zero balance at the end of the year. In the beginning, the Service Center will run a deficit as parts bought are not paid back until later. After a few years (in our case, this has to be done within 3 years due to NASA contractual requirements), the Service Center will "break even". This can actually be done sooner using more conservatism in income rates and replenishment expenses.

The "right" stock–Clearly the most important consideration is to inventory the "right" hardware with the characteristics of relatively low investment risk, low obsolescence and high customer use. The review process to select this hardware and maintain the "right" inventory is crucial.

Future Opportunity: NASA Task Order

In the future, FHLP hopes to develop a Task Order with NASA that will enable a similar funding mechanism that internal Service Centers have done, but for much higher payoff hardware to Projects. Since the initial investment is much more substantial (typically greater than $50k-$100k each) than for the low cost Service Center items such as electronic parts (typically less than $10-15k each), the risk must be underwritten by our customer.

Even more important in this Task Order approach is the identification of appropriate hardware to invest in since the stakes are much higher. Where virtual inventory (e.g., supplier agreements) can be done, this will mitigate this risk. This approach would increase strategic planning of common hardware across multiple projects.

4. Supplier Agreements

Concept

Supplier agreements are created for the purpose of developing virtual inventories. These can be any kind of agreement with suppliers that improves the delivery of flight hardware. Examples include Blanket Purchase Agreements (BPAs) that are pre-negotiated contracts with suppliers, supplier-provided residual inventory lists and inventory, and advance work performed by suppliers (e.g., advance parts buys).

Rationale

Since all procured flight hardware comes from suppliers (distributors or manufacturers), developing more effective strategies that affect the supply chain is an important contributor to reducing hardware lead-time. Development of supplier agreements reduces hardware procurement lead-time since these agreements are made in advance and all agreed actions can be started in advance of project need, thereby eliminating this portion of the procurement time.

Approach

The principal approach used to date is the pre-negotiation of contracts, often referred to as Blanket Purchase Agreements (BPAs). Some companies may call these Open Purchase Agreements or General Purchase Agreements. BPAs can be established for a defined or general class of products and/or services. The more definition provided up-front, the more that can be pre-negotiated, such as price and delivery time.

Another approach that has been used is to obtain lists of available inventory at the supplier. These lists can be easily updated frequently if Internet links are provided. Typically this inventory is the result of overage from other orders. An expansion of this concept could include planning or building of product for other customers so that projects can take advantage of procurement "synchronized" with other customers.

A more complex supplier agreement would be pre-negotiated advance work performed by the supplier. This could include advance material procurement, partial build, complete build and advance inventory. The degree of supplier investment will be proportional to the expected return. This return can be increased through improved customer need forecasting, increasing the quantities procured or increasing the market share for the supplier. For higher supplier investment, the customer may have to contribute some up-front funds as well.

Examples

Mag-3 Power Converters–FHLP worked with the Electronic Parts Engineering Office to create a BPA for hybrid DC/DC power converters that provided converters for 5 different projects, saved many weeks of procurement and focused engineering and assurance resources on a strategic supplier, Magnitude-3 (Mag-3). Power converters are typically not specified until the customer determines what power, voltage and output values are needed, in large part due to the relatively high cost of these parts (from $5k for a space-commercial part to more than $20k for a radiation-hardened high reliability part). A representative picture of this hybrid part provided at the manufacturer's web site is shown in Figure 6[3].

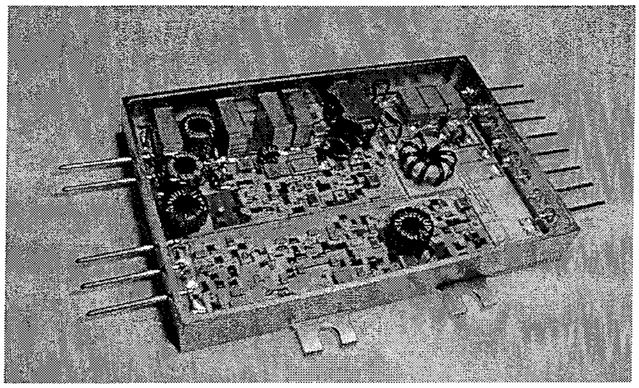


Figure 6 – Mag-3 Power Converter

3 of the 5 projects initially planned separate procurements until FHLP worked with these projects to get agreement to use a BPA, with each of their separate orders as an Order Release against the BPA. As the 2 new projects required Mag-3 converters, new Order Releases were developed to address their needs.

Results

This BPA saved each project from the contract initiation process that typically takes 2-4 weeks, as well as the shared effort of a single contract. A BPA "mini-audit" was also done by the appropriate technical, project and assurance personnel which saved considerable effort over each project doing this on their own.

Lessons Learned

One lesson learned is that it is important to maintain the supplier agreement once it is established. For BPAs, this means using the BPA, while for on-line inventory lists, this means ensuring the lists are periodically updated.

Future Opportunity: Space Logistics Consortium

An exciting future opportunity is the Space Logistics Consortium, in which FHLP serves as the bridge between a community of users and suppliers interested in space hardware. This would provide significantly increased leverage for the users with the suppliers for this relatively niche area. A crucial element in making this work is security: protecting user hardware information from other users, since many users compete with each other and this information might reveal competition-sensitive data.

5. Residual Inventory

Concept

The residual inventory program is an initiative to *efficiently re-utilize residual inventory from launched projects to save material cost and eliminate lead-time.*

Re-utilization of hardware is an idea that is not new; rather, the problem is efficiency. The nature of spacecraft hardware is that much of it can be re-used while at the same time much of it cannot as missions often utilize specialized designs with hardware that is unique to that mission.

The problem is balancing between excessing (the government process for dispositioning unneeded material) hardware that could have been re-used, and creating a large infrastructure to keep all hardware, some of which will never be used.

FHLP has created a system that integrates engineering, design, manufacturing, procurement, quality, logistics and financial processes to form a synergistic team that provides hardware as efficiently as possible.

Rationale

The residual inventory program reduces project costs by supplying hardware to projects at a minimal cost (FHLP labor to deliver hardware) and with virtually no lead-time. Not only does a project save the cost of the hardware itself, much of the development costs can be eliminated as well including design, procurement, integration and test, and support costs associated with these activities. A large part of the savings depends on the condition of the hardware received into FHLP. Certified hardware with appropriate pedigree and quality seals might be used as-is, whereas hardware with unknown history may require re-test, re-qualification or waivers.

Approach

The residual inventory process life cycle is demonstrated in Figure 7. As shown in the blue-boxed steps prior to and just after launch, the cycle starts at the beginning of a project during the proposal phase and continues through the planning, design process and finally, launch. During this time, use of FHLP inventory (common buys, anticipatory buys, supplier agreements, and residual inventory) is included in the planning and design process. During the proposal phase, projects can identify residual hardware to be used, reducing the cost of the proposal. During the design phase, projects request and obtain the hardware which yield cost, schedule and technical risk reductions.

[3] Magnitude-3 Website provided picture

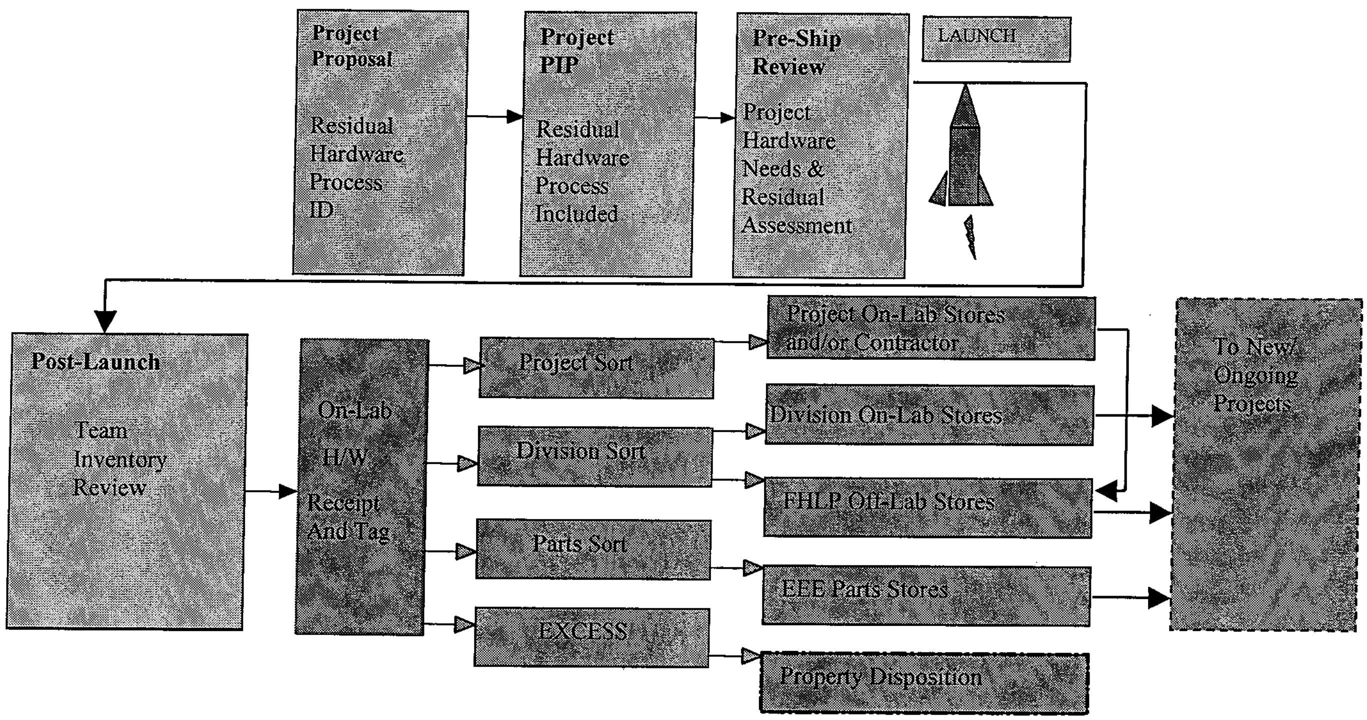


Figure 7. Residual Inventory Life Cycle

Additionally, part of the planning process is identifying that residual inventory will be sent to FHLP after launch. The green graphics in Figure 7 describes how the hardware flows through the residual inventory capture and registration process after launch until it is requested again by a project during the proposal and design phase, starting the cycle again.

After launch, JPL and its subcontractors have millions of dollars of hardware left over that is not utilized for flight, reflight (as applicable), operations-phase testbeds or testbed spares. This hardware may or may not be valuable to a future project. *The key is to capture the valuable hardware in a way that the cost of capture is significantly less than the hardware value to a future project.* FHLP captures this residual hardware from 3 sources:

1) Electronic parts residual inventory
2) JPL subassemblies residual inventory
3) Subcontractor residual inventory

All electronic parts at JPL are bought through the Flight Electronic Parts Service Center (FEPSC). Some are bought utilizing anticipatory buys and supplier agreements. Others are bought in response to specific project requests. Due to minimum buy and spares requirements, there are often parts that are not used by the requesting project. Once the project is complete, these parts become residual inventory and are available to new projects. This inventory is stored, controlled and managed with all other parts through the JPL parts database called Electronic Parts Information Network System (EPINS). The cost of maintaining and supplying this residual parts inventory is minimal since is an integral part of the electronic parts supply business from the beginning.

JPL and subcontractor subassembly level hardware are treated similarly. After a mission has launched, FHLP works closely with property management, contracts management and the subcontractors to generate comprehensive property lists that contain all unneeded hardware. The lists are reviewed by Subject Matter Expert (SME) teams in each subsystem category: Attitude Control, Command and Data Handling, Mechanisms, Power, Propulsion, Pyrotechnics, Structures, Telecom, Thermal, etc. to identify residual hardware that may be valuable for future projects. These technical division experts already have a vision into the future as they are designing current missions and are thinking about future ones. The chosen items and their pedigree are sent to FHLP for staging (decomposing from a complete shipment to individual items in stages) and storage. This process assures that the most critical items are delivered to FHLP Bonded Stores and time and space resources are not spent on the less valuable items.

During the SME review process, key information is collected to better understand the value of the hardware and to pass this information on to the customer. This includes administrative and technical information such as part number, serial number, past project, cognizant engineer, storage requirements and very importantly available pedigree.

The hardware is also rated as flight or non-flight. Hardware received as flight will generally retain its flight status. Some hardware may be reused, but due to condition, design, or other issues, will be retained for non-flight engineering development activities.

The hardware's estimated replacement cost, lead-time, probability of re-use (low, medium, high) and final disposition (user/project retain, store or excess) are determined. A low probability of re-use rating will most likely cause the hardware to be excessed, reducing infrastructure required to maintain it. A high rating will initiate a review of the hardware to assure proper pedigree, packaging and storage conditions are maintained so that it can be re-used with the minimum effort. A medium rating will cause the hardware to be retained and stored, but no further effort will be put forth until the hardware is needed.

This information is also used for metrics to help monitor performance and determine future guidelines for hardware retention and use. Metrics are generated in several key areas, such as value, lead-time, cost-benefit, usefulness, and project penetration.

Registration and Storage–Once the hardware is reviewed and the appropriate disposition is made, FHLP registers (logs it, takes picture, assigns unique F# barcode) and stores the hardware. The key to registration and storing is to have a cost effective system, retain control, and make the hardware accessible to the customer.

FHLP has developed a registration and storage process that utilizes current JPL business processes, systems and resources. Upon receipt, FHLP stages the material and sorts it by subsystem The hardware is registered and stored in FHLP Bonded Stores (Figure 8) utilizing the JPL Oracle-based NBS (New Business Solutions) Assets property management system. This is a simple process that utilizes a bar code for the hardware, location, and owner. FHLP uses an F00000X tag (for "Flight") sequence to differentiate from other property. The hardware is scanned into the system and is displayed in the owner's inventory. At any time after that initial entry, the hardware can be moved to new owners and locations on line with acceptance/rejection mechanisms in place to assure both current and future owner agree with the transaction. Additionally, a move request to the transportation group can be generated on line if required.

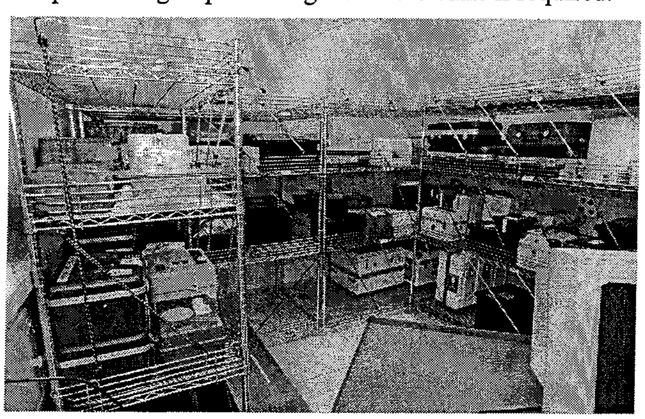


Figure 8. FHLP Bonded Stores

The material information taken during the SME review; namely the hardware location and owner information as well as a digital picture are then loaded into an intranet catalog available on-line to all JPL personnel. The catalog contains all available hardware information and is discussed in detail in the *Hardware Information Section* below. This is all done with support from JPL institutional resources.

Every year thereafter the hardware is re-evaluated for probability of use, value, and other characteristics that define its value to the customer assuring that the hardware and information about it are current. Additionally, all hardware that is no longer deemed useful is dispositioned as excess so that resources are used on the remaining critical hardware.

Example

The Mars Rover Software Development Unit, Rocky IV (Figure 9) is a good example of valuable hardware re-used for development. After being used on Mars Pathfinder and again on Mars 01, its probability of use was estimated as low and it was planned for excess. The Rover's replacement cost was estimated at $750,000 and since it appeared prudent to store this for some time, FHLP registered it. Within 3 months it was requested for use by the Rover development program and used as a baseline for a rover scaling study.

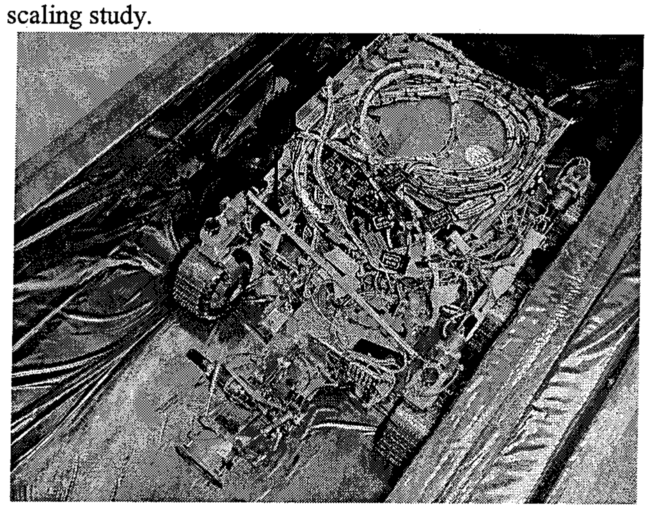


Figure 9. Rocky IV Software Devel't Rover

Results

The following statistics show some of the data collected for residual inventory. Over $1.5 million worth of residual inventory was delivered to 18 projects in FY01. A summary of the items delivered follows:

Quantity of Projects Supported	18
Quantity of hardware items delivered	59
Cost Savings of hardware items delivered	$ 1,048,900
Quantity of Electronic Parts delivered	10,879
Cost Savings of Electronic Parts delivered	$ 510,837

A summary of the current inventory not including electronic parts follows. Over $34 million is currently available in inventory for use by projects.

Quantity of projects in inventory	25
Inventory value	$ 34,459,370
Total quantity of items in inventory	1340
Inventory line item quantity	448
Average age	1994

Additionally, the current available electronic parts inventory exceeds 1.3 million items and has a value of over $23 million.

The value of delivered residual inventory metric (Figure 10) shows the value of that inventory, including electronic parts, delivered over time. This metric has a large spike in July 2001, caused by the rover delivery. The delivered lead-time profile metric (Figure 11) shows the lead-time saved of the subassembly hardware delivered (electronic parts data not available at press). The inventory value by subsystem metric (Figure 12) shows the value of all items in inventory by subsystem, totaling almost $35 million. Note that comprehensive SME reviews have been completed on 3 of the 14 subsystems, so the data is partial.

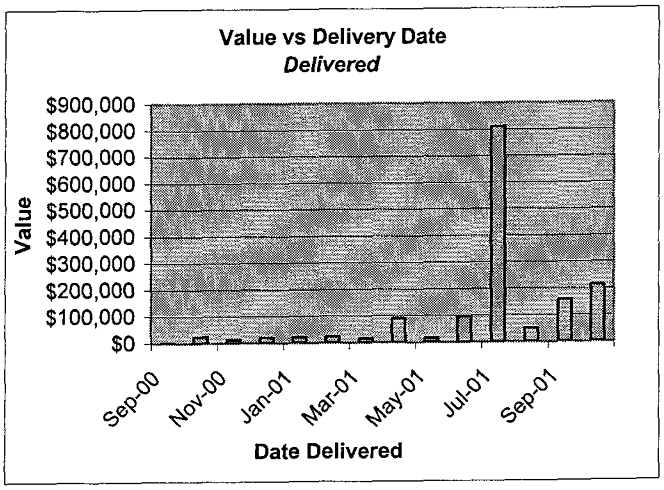


Figure 10. Delivered Value

Lessons Learned

Pedigree – Pedigree is an important contributor to hardware value. Request all pedigree early in the capture process to assure it stays with the hardware. Maintain a unit history log for hardware taken out of inventory.

SME Reviews – Hold SME reviews early in the process to ensure valuable hardware is captured and to help spend as little resources as possible on non-valuable hardware.

Electronic parts – From FHLP's initial experience, the cost of capturing parts with sufficient pedgree is high compared to its acquisition cost.

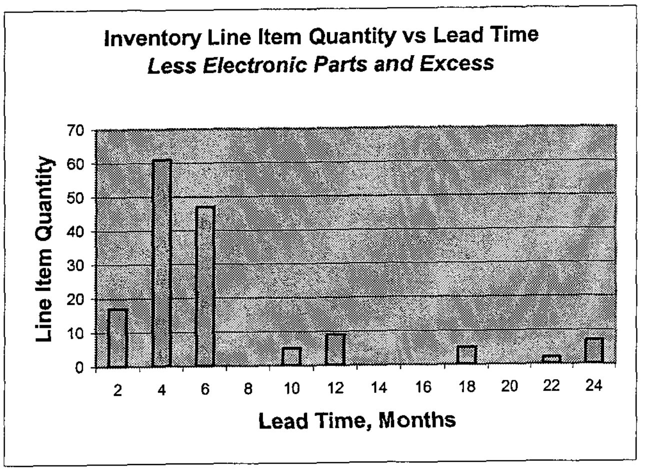


Figure 11. Delivered Lead Time

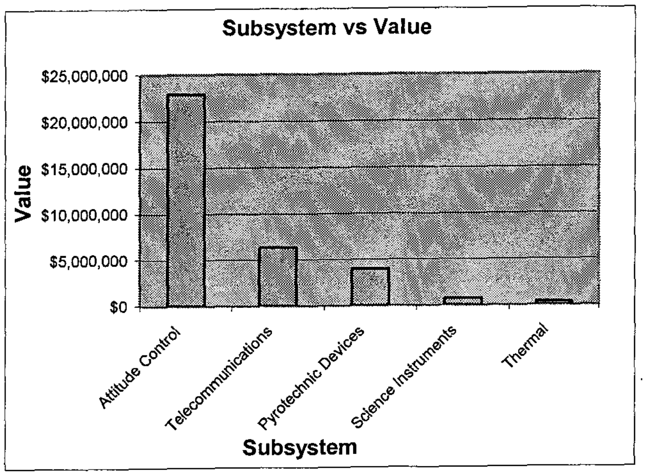


Figure 12. Inventory Value

Future Opportunity: Flight Material Management System

An integrated process/system for controlling and tracking flight material within JPL is the future Flight Material Management System (FMMS). This system will begin with the hardware supplier providing a tracking mechanism (e.g, bar-code, matrix-code directly marked on the hardware) that can be used throughout the hardware's life cycle. All processes that interact with this hardware will be able to be tracked with FMMS. FMMS will also be interface to configuration management, property management, logistics services, and hardware safety systems for greater synergy between support organizations. An automated storage facility will be environmentally controlled and secure. Hardware inventory, records and design information will be available on line.

Implementing FMMS will continue to decrease the cost and lead time of hardware and information, by making it more readily available. It will increase the quantity and availability of material records and technical information and therefore increase the probability of hardware use. It will increase the accountability and safety of hardware, also increasing the probability of hardware use. And finally, it will enable missions that otherwise might not happen by providing more material at low cost and risk to the projects.

6. HARDWARE INFORMATION

Concept

FHLP's charter is to reduce the lead time and cost associated with material used by flight projects. It performs this function by creating a real and virtual inventory of flight hardware and providing information about this material to designers and projects. Real inventory consists of residual inventory available from prior projects and tangible inventory from ongoing procurements, such as common buys. Virtual inventory consists of supplier agreements, such as open contracts for material, vendor/distributor residual inventory and unallocated material from ongoing procurements yet to be delivered. FHLP provides availability information about material in these real and virtual inventories to proposers, designers and projects in order to enable new missions, speed development time, and reduce cost and risk.

Rationale

The objective of the FHLP information system is to provide comprehensive access to flight material in order to decrease the development time and cost for flight systems. The principle information provided today is availability of flight hardware under the cognizance of FHLP through the FHLP Catalog. Capabilities for selection, request, common procurement, allocation, delivery, and replenishment of the FHLP inventory are provided by this information system, as well as a library of relevant product documentation and records.

Approach

An integral part of FHLP is providing customers access to hardware and technical information. FHLP has developed a website that provides this information to all internal JPL

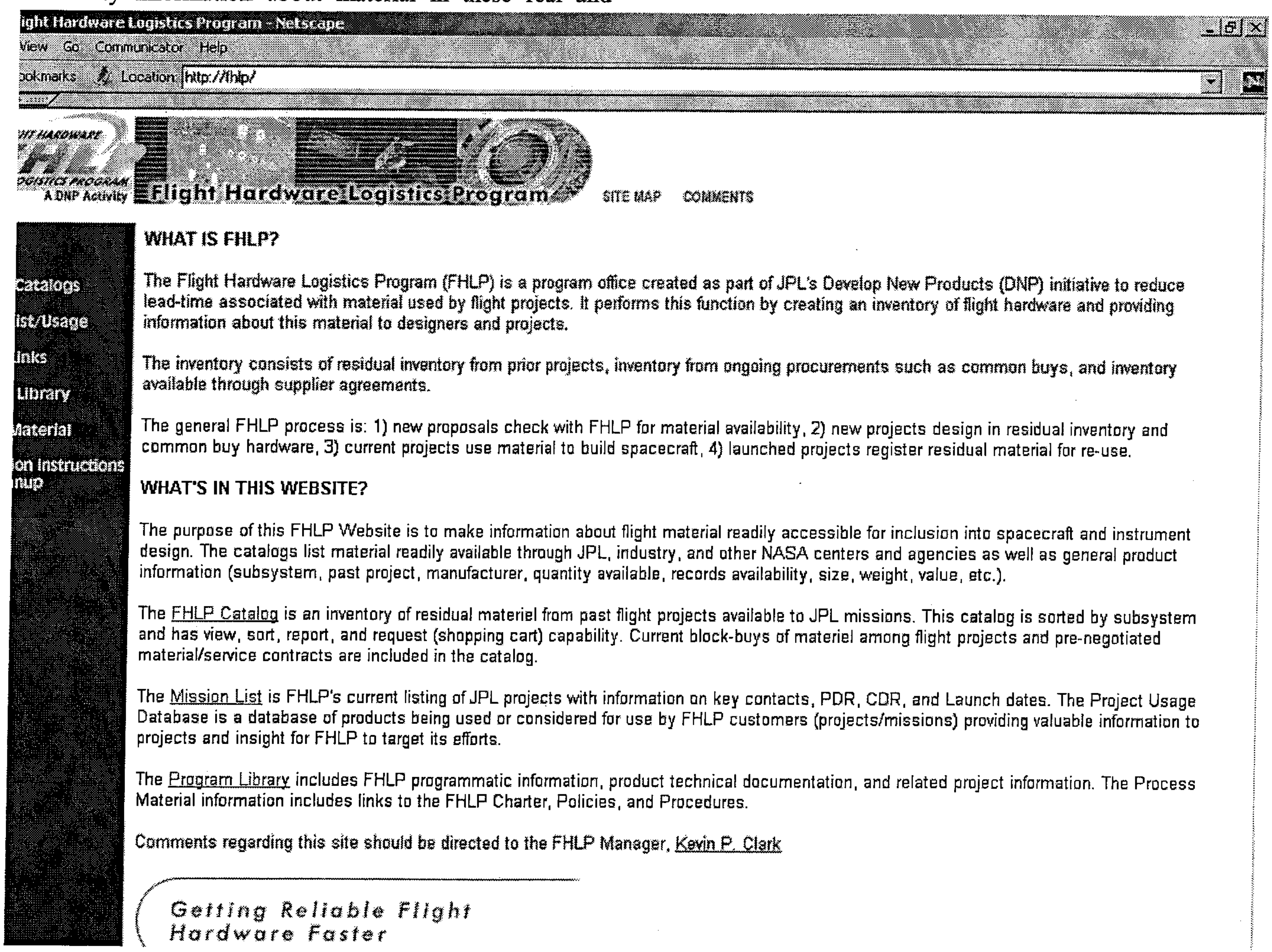


Figure 13. FHLP Website

customers instantly (Figure 13). The overall FHLP information system architecture is shown in Figure 14. This site is organized as follows:

1) Materiel Catalogs
2) Mission List
3) Project Usage Database
4) Program Library
5) Process Material
6) Comments – send email to FHLP process owner

The principle interface for the user is the ***FHLP Catalog,*** which is a centralized FHLP-controlled database of real inventory that FHLP has cognizance of, whether FHLP or users are storing it. It is driven by JPL's NBS (New Business Solutions) Oracle Assets module, which provides the interface to all users to control their own assets. The catalog houses all information on current FHLP inventory, including its control number, part number, quantity, manufacturer, previous project, cognizant engineer, available pedigree, and a digital picture (Figure 15).

The catalog is organized by subsystem, so that the user, typically an engineer, can easily locate the hardware required. It has the capability to sort by any data field such as part number, previous project, etc. It also has a report capability with standard report options as well as personalized options. The reports can be exported to Microsoft Excel so the user can manipulate, send and utilize the soft copy as desired.

The catalog also has a shopping cart capability so that the user can request several items of hardware on-line. The request sends an e-mail message to FHLP that the items have been requested and an automatic response is sent to the requestor that FHLP will respond within a week regarding the availability and shipment of the hardware. If more than one customer requests an item, FHLP will help negotiate a resolution and generate an MOU documenting the agreement.

Another capability of the catalog is its link to the Electronic Parts Information Network System (EPINS) inventory of electronic parts and connectors that are available for projects to use. FHLP has created a link to this database with extensive search capabilities for parts. The user can search by single or multiple characteristics of a part, such as part number, description, generic part number, manufacturer, or package. It also allows a search of value, rating, and tolerance, using a specific value or a range to find a specific part in stock, or a range of parts that might be acceptable.

Another integral part of the website is the *Mission List and Project Usage Database (PUD)* as discussed in the Common Buy section. The Mission List (Figure 4) describes FHLP potential customers and helps prioritize and plan future activities such as: support to projects during the

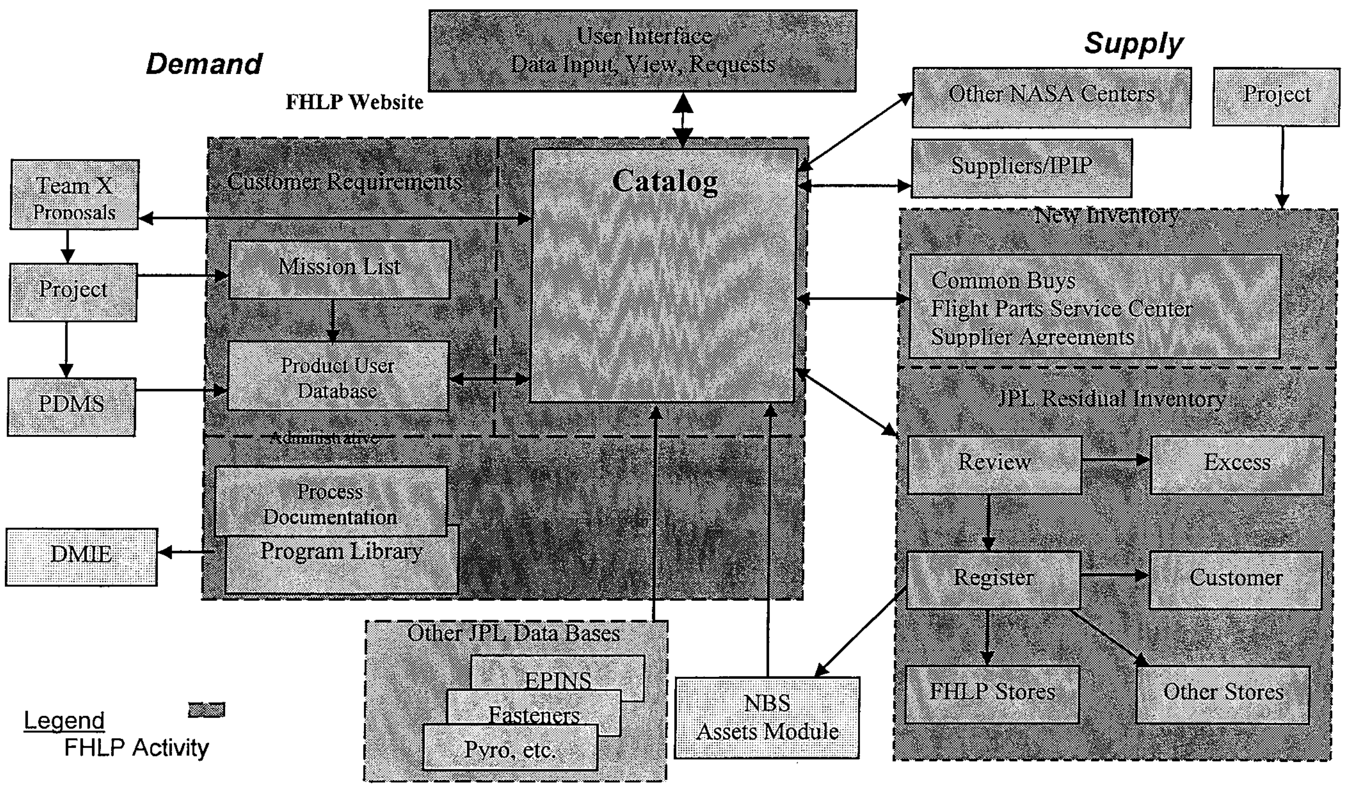
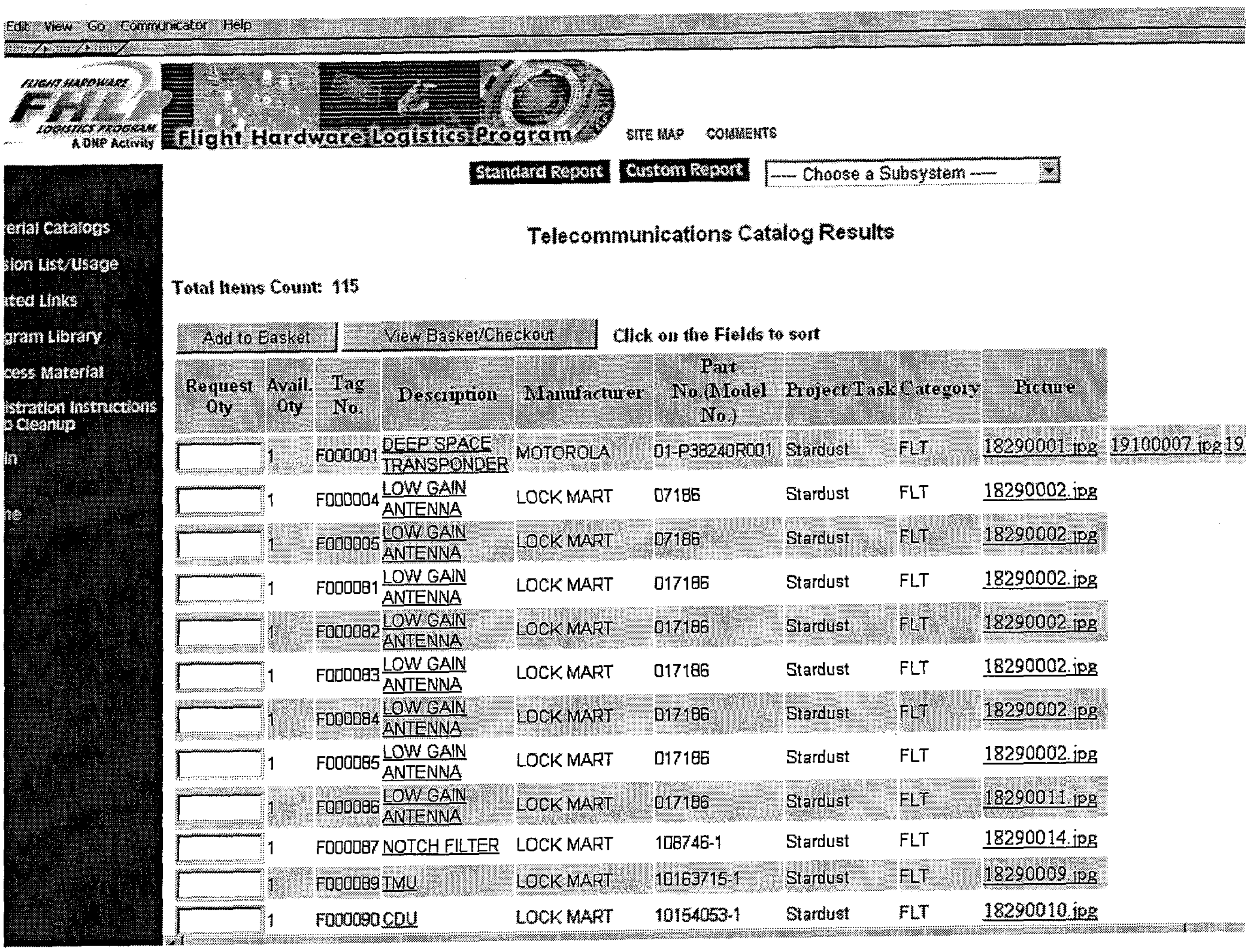


Figure 14. FHLP Information System Map



Request Qty	Avail. Qty	Tag No.	Description	Manufacturer	Part No.(Model No.)	Project/Task	Category	Picture
	1	F000001	DEEP SPACE TRANSPONDER	MOTOROLA	01-P38240R001	Stardust	FLT	18290001.jpg 19100007.jpg 19
	1	F000004	LOW GAIN ANTENNA	LOCK MART	07186	Stardust	FLT	18290002.jpg
	1	F000005	LOW GAIN ANTENNA	LOCK MART	07186	Stardust	FLT	18290002.jpg
	1	F000081	LOW GAIN ANTENNA	LOCK MART	017186	Stardust	FLT	18290002.jpg
	1	F000082	LOW GAIN ANTENNA	LOCK MART	017186	Stardust	FLT	18290002.jpg
	1	F000083	LOW GAIN ANTENNA	LOCK MART	017186	Stardust	FLT	18290002.jpg
	1	F000084	LOW GAIN ANTENNA	LOCK MART	017186	Stardust	FLT	18290002.jpg
	1	F000085	LOW GAIN ANTENNA	LOCK MART	017186	Stardust	FLT	18290002.jpg
	1	F000086	LOW GAIN ANTENNA	LOCK MART	017186	Stardust	FLT	18290011.jpg
	1	F000087	NOTCH FILTER	LOCK MART	108746-1	Stardust	FLT	18290014.jpg
	1	F000089	TMU	LOCK MART	10163715-1	Stardust	FLT	18290009.jpg
	1	F000090	CDU	LOCK MART	10154053-1	Stardust	FLT	18290010.jpg

Figure 15. FHLP Catalog

proposal phase; developing anticipatory and common buys during preliminary design; supplying hardware during the build phase; and capturing residual hardware after launch.

The *Project Usage Database (PUD)* is organized in a hierarchical product breakdown structure to the component level that decomposes the FHLP Mission List into elements (subsystems), then into component types (e.g., transponders, antennas) and finally into the products (e.g., RAD6000 computer) themselves with information about the product maintained at the lowest (product detail) level. An output from the PUD is shown in Table 2. This information is used to:

1) Help FHLP explore common design and hardware opportunities on current projects.
2) Help proposal customers find hardware used on past projects to determine technical requirements, cost, and lead time of hardware.

The ***Product Library*** is a collection of FHLP programmatic, product, project, and technical information organized in Docushare (library tool from Xerox). Information relating to specific projects or missions can be found in the "Projects" folder, such as residual inventory available for use on MER. Technical data on FHLP products such as the RAD 6000 Flight Computer can be found under the "Products/Parts" folder. Other FHLP programmatic information including presentations can be found in the FHLP Overview, Information Systems, and Presentations folders.

The library also has connections to technical websites generated by others at JPL. The best example to date is the Flight Equipment Database (http://fed.jpl.nasa.gov) internal website, generated by a JPL engineer. The website organizes information about flight hardware in a manner that makes sense to a typical engineer and includes valuable technical and lessons learned information that could save current and future engineers time.

The Process Material link includes FHLP released policies and procedures such as a Charter, User Guide, Transfer of Project Material (Residual Material), Expansion of Inventory (Anticipatory Buys), Brokering of Consolidated Material Buys (Common Buys/Supplier Agreements), and an Internal Operating Procedure. Informal procedures helpful to users such as how to hand-carry flight hardware off-lab can be found here and also in the "FHLP Process Collection" folder in Docushare.

Example

The website and catalog are continuously used to find material and information for projects. For example, an engineer looking for a Mars Pathfinder Altimeter for possible use on MER was able to search the catalog for that item. He could have searched the catalog by sorting for part number, but he didn't have the part number. He could have also searched by description, but he didn't know the exact name. So he searched by previous project, scanned through the available items until the desired item was located. During the scan, he also noted that there were some related antennas that he needed. The items were delivered the day that they were required and scanned to the new owner and location. Total cost for the search and delivery was approximately two hours for hardware worth about $15,000 with a lead-time savings of 9 months.

Lessons Learned

Data Availability – There are many databases that exist but are not available to those who need them. Identification of these databases and plans to make critical data available is an important contribution. There is also more technical information on key products required.

Integrated data – Databases are not linked or available to users in a single location. Significant time is spent by engineers looking for current and accurate information. Also, proposal teams require certain information quickly. A further improvement would include synthesis of available data from different communities to increase information content, such as linking application experience (user) with technical specifications (developer).

Future Opportunity: Hardware "Information Central"

Vendor links, Fact Sheets, Summary Sheets, JPL Technical Division information, Vendor information, Industry Product Information Process (IPIP) - Dan Thunnissen, CSMAD (Center for Space Mission Architecture and Design), Proposal Center databases, Product Data Management System, Hardware inventories linkage, Product Attributes Database, Heritage information, Web-bots

As FHLP and its corresponding information system grows over time, this will serve as the ultimate portal for information about material needed for development of space systems. From its current foundation of availability information for known flight inventory, it is expected to grow to include:

In the short term, links to other JPL hardware databases:

1. Propulsion database –Access database of hardware in propulsion bonded stores.
2. Fasteners database –Database in Smart Shop of fasteners used to build flight and prototype hardware.
3. Pyrotechnic devices –Microsoft Word log data of pyrotechnic devices.
4. DSN database –Database that contains over 7000 inventory items used by the DSN.
5. NBS – Oracle Acquisition and Assets module linkages.
6. Proposal Center databases

And in the long term, links to additional hardware and information:

1. Additional Technical information (e.g., design data, specifications, Fact Sheets, Summary Sheets)
2. Product Data Management System
3. Vendor information (e.g., application notes, alternative parts)
4. Industry Product Information Process (IPIP)
5. Supply chain information (e.g., suppliers, common buys, open contracts)
6. Application information
7. Heritage/pedigree information
8. Search capability across multiple inventories

The FHLP information system has to interface with many JPL and contractor technical and business systems, including configuration management, acquisition and logistics. On the demand side of FHLP information systems, it is important for FHLP information to become fused into the design process and development systems so that this centralized information is provided seamlessly to design databases without designers having to search for it. On the supply side of FHLP information systems, it is important to provide an effective channel between flight hardware suppliers and the users. Consortium procurements with competing companies through FHLP will require secure handling of usage information. Eventually, automated "agents" will seek optimum logistics solutions to project supply problems, new technology products (including their respective qualification cycles) will complete the virtual inventory and FHLP will be expanded to include services and software needed for flight development.

7. Project Support

Rationale

Project Support is the end product of the every segment of the Flight Hardware Logistics program. The FHLP as part of the Project Planning Office is dedicated to supporting projects during the planning and proposal development phase, and also through the entire life cycle of a project

(Figure 16). This allows the engineering team to concentrate on design, while FHLP concentrates on providing technical information and hardware.

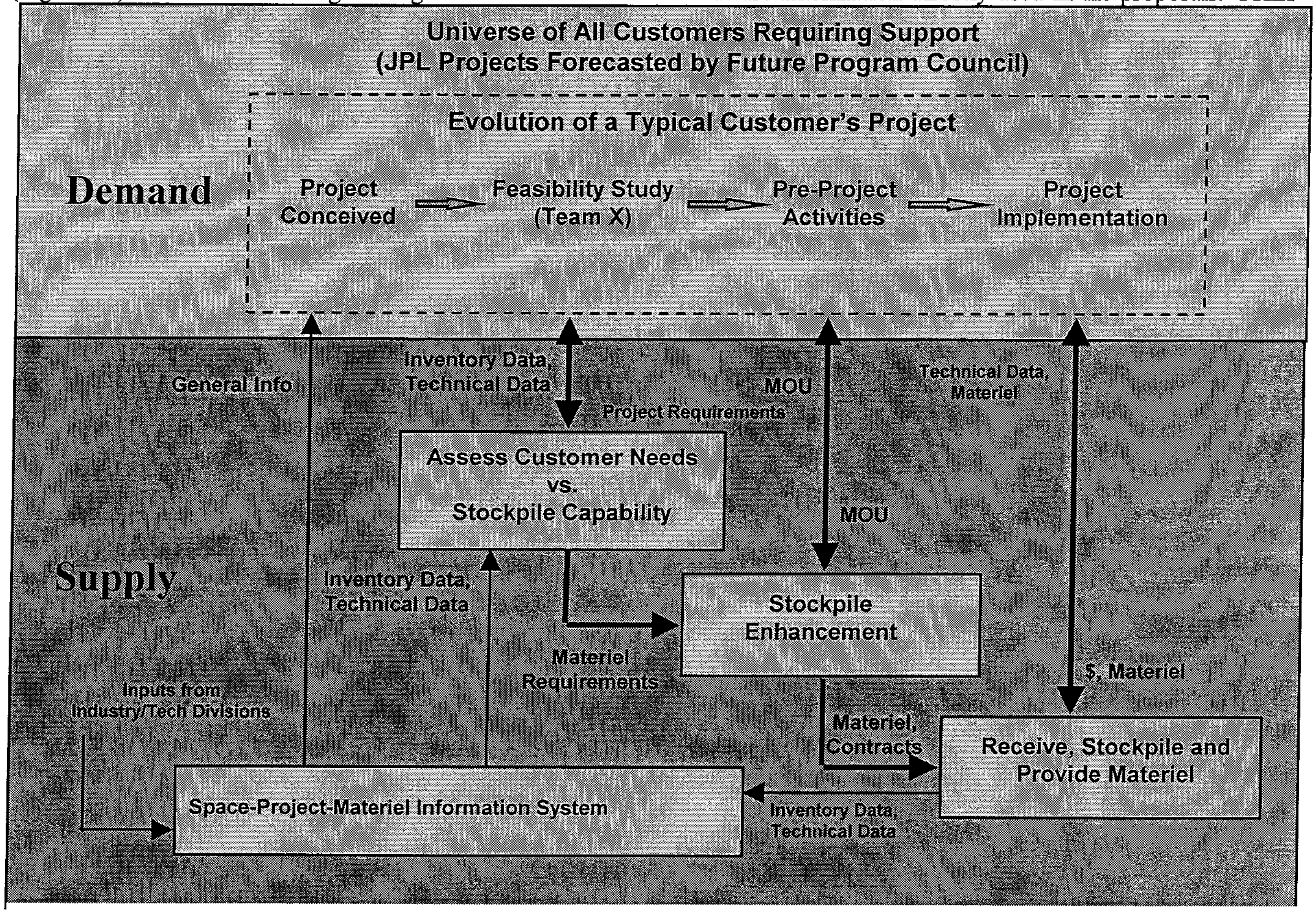


Figure 16 – FHLP Project Support Life Cycle

Concept

The goal of FHLP is to support projects with hardware, information, and services as efficiently as possible. This means having easy access to the following:

1. critical hardware
2. long lead hardware
3. low/no cost hardware
4. technical information
5. logistics services

FHLP has and continues to work with Technical Divisions, Configuration Management, Quality Assurance, Systems Safety, Records Management, Property Management, and Logistics Services, to develop innovative processes and systems to support this goal.

Approach

Proposal Phase–During the proposal phase, FHLP provides real time support to proposal teams by supplying valuable hardware information directly used in the proposals. FHLP works with each subsystem designer to understand what type of spacecraft and hardware is being proposed. With that information, FHLP researches the residual inventory and anticipatory buy inventory for available hardware, whether for flight or engineering development. Additionally, FHLP researches other current missions for hardware that may come available or similar missions for common hardware, or common hardware design opportunities. Finally, FHLP provides technical information of past or current missions that might be helpful with the proposal, including hardware cost, lead time, technical specifications, or other critical requirements.

Design Phase–During the preliminary design phase, FHLP provides hardware and hardware information to engineers and designers. During preliminary design, technical information on past and current projects is helpful in defining requirements and specifications for new designs. FHLP can help projects find this information and utilize the associated hardware for breadboard and engineering hardware. If a project requires specific hardware, FHLP can search the available residual, anticipatory buy, common buy, and supplier agreement inventory for that hardware, provide pedigree as required, and provide logistics support for movement.

FHLP will also work with the projects and subsystem experts to identify possible common buy opportunities with other projects. FHLP will coordinate the technical discussions, contracts management, and delivery of this hardware (see detail in the Common Buy section). FHLP will also perform lead-time analyses for parts and hardware to determine anticipatory buy opportunities and coordinate discussions with the Parts User Groups for facilitating high quantity buys with other projects (see details in the Anticipatory Buy section). Finally, FHLP can generate supplier agreements with key suppliers by completing the procurement and contracts in advance to help reduce procurement cycle time (see detail in Supplier Agreement Section).

Build and Test–During the build and test phase, FHLP works with the projects to deliver hardware and support with technical issues. During test and analysis, FHLP will help coordinate the activities with suppliers and subcontractors. If the hardware requires movement to non-JPL facilities, FHLP will coordinate with contracts, transportation, security, and quality to assure hardware is delivered quickly and safely.

Operations–After launch, FHLP works with the project to disposition residual material as part of the closeout process (see details in Residual Material). FHLP also supports projects with other logistics activities including movement and storage of flight hardware and equipment that might be required later during operations. FHLP has even worked with the projects to move the models to museums for display, including the Mars Rover (Marie Curie) to the JPL Visitors Center and the Cassini Mockup a museum, yet to be determined.

Examples

FHLP has provided support to 8 proposal teams, providing common buy opportunities, residual inventory recommendations, hardware information, and cost and lead time estimates, saving the proposals time, cost and improving proposal accuracy.

Additionally, FHLP has provided logistics support to projects in their implementation phase. Some examples are

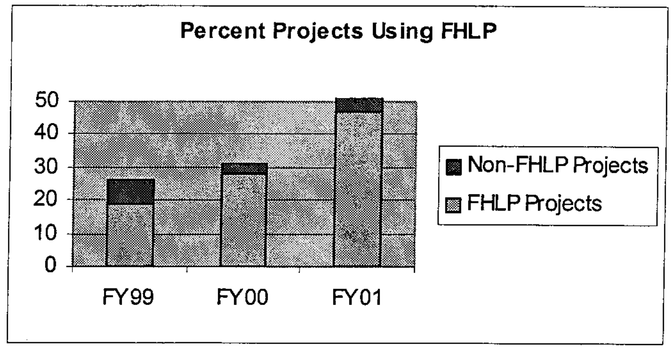


Figure 17 - Projects Supported

coordination and delivery of FHLP common buy flight computers for MER and Deep Impact to off-site facilities to support development testing, saving valuable engineering time during critical phases of the program.

Finally, FHLP has supported projects in their operations phase. Examples of this include the provision of residual parts for Cassini testbed enhancement and storage of residual hardware for a range of operational projects.

Results

FHLP has provided project support to 47 projects in FY01 (Figure 17). This included support to common buys, anticipatory buys, residual inventory delivery, material information, proposal support, and residual inventory capture during project closeout (Figure 18).

FHLP sent out a survey at year end to 86 key customers in FY01 to provide information on performance and suggestions for improvement. The resulting 50% response

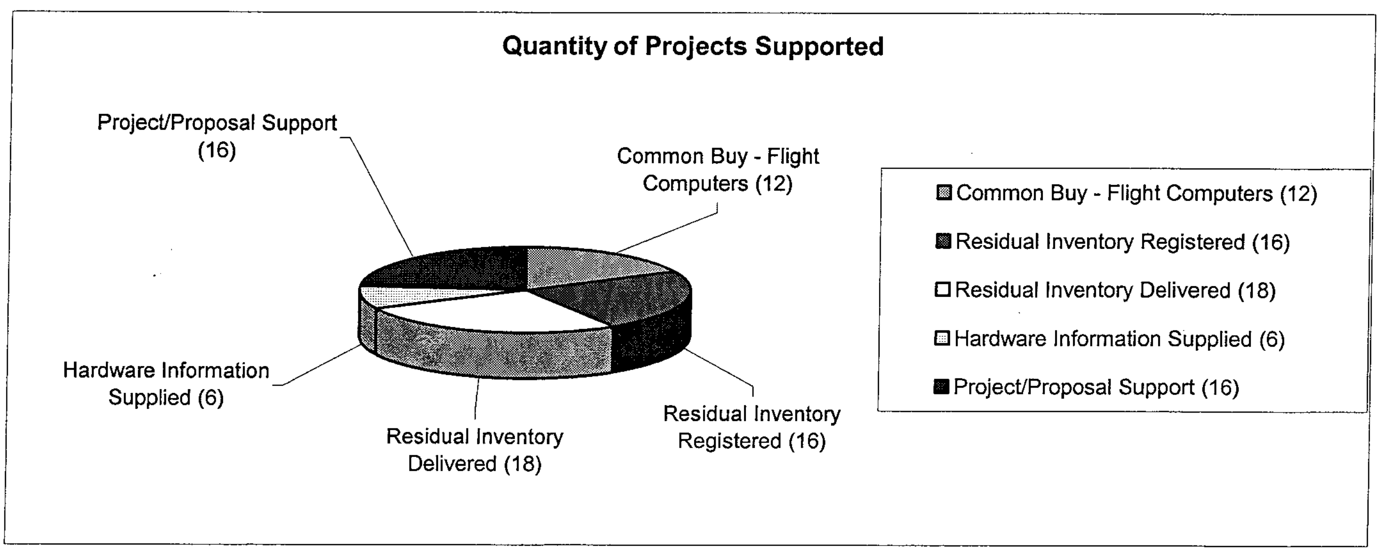


Figure 18 – FHLP FY01 Projects Supported

rate was very positive and generated a score of 4.5 out of 5.0. More valuable however, were the identification of the most valuable activities and suggestions for improvement which will help drive our plans for FY02 and beyond.

Lessons Learned

Rapid proposal team response – Proposal teams work so quickly that support must be proactive, or they will not be able to use the information.

FHLP Procedures – FHLP logistics support to projects must have very clear procedures, forms and examples. The infrastructure process created by these "lean and mean" procedures may be implemented by FHLP, engineering, business and project personnel.

Future Opportunity: Integrated Technology Development

The technique that FHLP employs to determine common project needs and match these to hardware capabilities and available inventory can be applied earlier in the technology development cycle. FHLP currently works only with hardware that is fully developed; however, the same commonality approach can help drive common project requirements towards a more efficient qualification of needed hardware. This could also aid technology developers in identifying potential funding sources.

New hardware development is often conducted in response to a limited set of future project requirements. Applying a systematic method to understanding and mapping out all the future potential projects' needs would provide the widest possible application of hardware and highlight the range of requirements so that the hardware developed will satisfy the maximum number of these future projects.

Additionally, FHLP's overall life cycle must include a good understanding of technologies in development, since many of these will be qualified hardware that proposals and project will need information about and delivery of by the time they are ready for implementation.

8. Conclusions

The Flight Hardware Logistics Program (FHLP) has generated and implemented a process to help Projects reduce schedule, cost and technical risk, through the synergistic combination of engineering and business best-practices. Although FHLP has made tremendous strides its goals to date, there are still tremendous opportunities for more breakthroughs in project development.

By focusing on and expanding the current initiatives of common buys, anticipatory buys, supplier agreements, residual inventory re-use, enhanced hardware information and ongoing proposal and project support, FHLP will achieve further breakthroughs in cost savings, lead-time savings, and risk reduction for projects. Improvements in these areas, such as a broader library of technical information, a more valuable inventory of hardware, a direct part marking inventory system, linking to other JPL and industry hardware databases, and partnering with other NASA centers will increase FHLP's capability to support projects. Similarly, expansion of our technical information database such as improved pedigree availability, expanded technical libraries of past and current projects, and links to supplier technical and specification databases, will provide the engineers additional information saving valuable time, both in cost and development cycle time.

FHLP will continue to discover innovative cost and cycle-time savings techniques that will utilize technical, business, and support functions to support JPL and NASA projects, enabling new missions and helping to make them successful.

Acknowledgements

The work described in this paper was carried out ~~by~~ at the Jet Propulsion Laboratory (JPL), California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The Flight Hardware Logistics Program (FHLP) is an institutional element of JPL's Project Planning Office under the Project Support Office that provides cross-cutting support to JPL projects.

Many other individuals provided invaluable data, insight and review of this paper including A. Amy Attiyah, Clint Erickson, Sanford Jones, R. Lloyd Keith, Elizabeth Romo, James Wincentsen and Larry Wright. In particular, special credit goes to Larry Wright, the "founding father" of FHLP.

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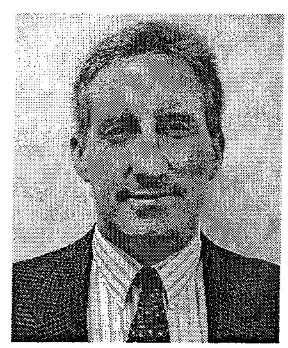

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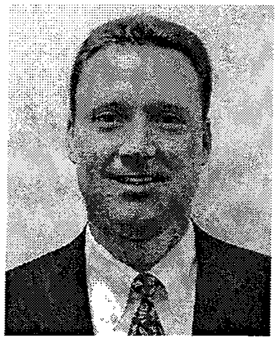

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